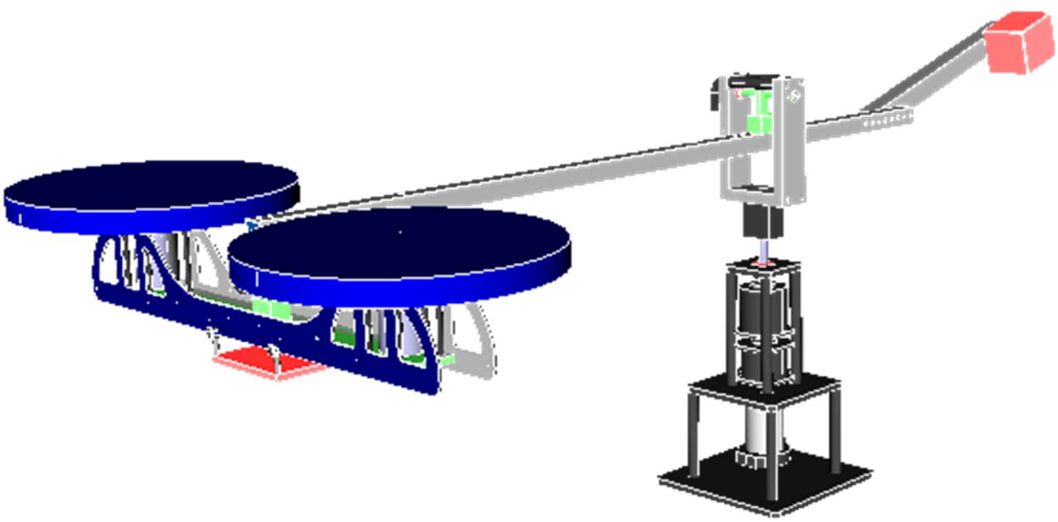
DEPARTMENT OF AEROSPACE ENGINEERING
FACULTY OF ENGINEERING, ARCHITECTURE AND SCIENCE

AER 715 AVIONICS AND SYSTEMS

Laboratory 4.1
Flight Control – Simulation



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Engineering Specialist: C. Chan **Instructor: Dr. G. Liu**

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1. Lab Instructions

- SAFETY FIRST – DO NOT PUT YOUR FINGERS OR ANY LOOSE ITEMS IN THE SERVOMOTOR GEARS.
- This lab is to be done **<u>in groups of two (2)</u>**.
- Download the lab manual, worksheet, and files from D2L and save them on the Desktop in a folder called LAB4.
- Read the instructions in the laboratory manual carefully and follow the specified procedures.
- Answer all questions in the provided worksheet.
- At the end of the lab, submit one lab worksheet along with the standard Ryerson Aerospace Assignment/Laboratory Cover Sheet. Each student must attend the laboratory and sign the Cover Sheet in order to receive a mark.

2. Flight Control - Simulation

2.1 Introduction

In Lab 3 we developed a mathematical model for the elevation dynamics (vertical) of the 3-DOF Helicopter using analytical and experimental techniques. In the following lab, the travel dynamics (horizontal) of the helicopter will also be analyzed and modeled. Note that because the pitching axis is still mechanically fixed, only the magnitude of the thrust vector can be augmented to produce motion.

In order to incorporate the travel dynamics into the Simulink models, an additional dynamic model will be inserted to the existing models for both simulation and actual experiment.

2.2 Purpose

The objective of this lab is to expand our current mathematical and experimental models of the 3-DOF Helicopter to include the travel dynamics. This also includes integration of said travel dynamics into our Simulink models used for both simulation and actual experiment.

At the end of this laboratory, you should understand the following:

- Mathematically model the travel dynamics of 3-DOF Helicopter
- Implement the model into Simulink from scratch using function blocks from the Simulink Libraries

2.3 Parameters of the 3-DOF Helicopter

The parameters of the 3-DoF helicopter are given in the following two tables:

Table 1: 3-DOF Weights and Measures

Symbol	MATLAB	Description	Unit	Value			
				Heli 1	Heli 2	Heli 3	Heli 4
M_h	Mh	Mass of Heli Body	[kg]	1.442	1.422	1.464	1.450
M_c	Mc	Mass of CW	[kg]	1.914	1.916	1.919	1.918
L_a	La	Distance from Pivot to Helicopter body centre	[in]	25.75			
L_b	Lb	Distance from Pivot to counterweight centre	[in]	18.125		18.5	
L_h	Lh	Distance from pitch axis to rotor center	[in]	6.985	6.932	6.995	6.933
J_e	Je	Moment of Inertia	[kg-m^2]	TBD	TBD	TBD	TBD
D_e	De	Viscous Damping	[N-m-s/rad]	TBD			
K_e	Ke	Spring Constant	[N-m/rad]	TBD			
F_t	Ft	Lift Force @ SLF	[N]	TBD	TBD	TBD	TBD

Table 2: Other Parameters and Limits of the 3-DOF Helicopter

Symbol	MATLAB	Description	Unit	Value			
				Heli 1	Heli 2	Heli 3	Heli 4
K_f	Kf	Motor-Prop Force Constant	[N/V]	0.140			
K_{rt}	Krt	Motor-Prop Torque Constant	[N.m/V]	0.0036	0.0032	0.0038	0.0027
ε		Elevation Range	[Degrees]	[~-26 to ~30]			
ε_o		Elevation Start	[Degrees]	-25.75			
λ		Travel Range	[Degrees]	0 to 360			
g	g	Gravity constant	[m/s^2]	9.81			
	KE_CNT	Encoder Resolution	[counts/rev]	-4096			
	KE_RAD	Encoder Resolution	[rad/count]	1.5340E-2			
	K_CABLE	Amplifier Gain	[V/V]	3		5	

2.4 Theory and Model

The top view of the 3-DOF Helicopter in the travel axis (located at Pivot B) can be seen in Figure 1, where λ is the (yaw) angle of rotation about the travel axis:

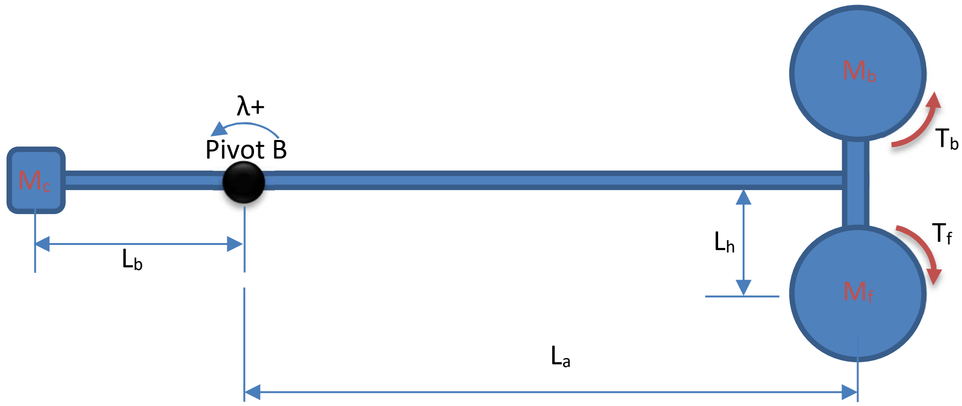


Figure 1 Helicopter Top View with Loading

By applying D'Alembert principle again to derive the dynamic equilibrium equation by finding the sum of all torques and inertia forces about the travel axis (Pivot B):

$$\sum_{B} T_i = T_b - T_f = J_t \ddot{\lambda} \qquad \textbf{Equation 1}$$

In Fig. 1, M_c, M_b, and M_f are the masses of the helicopter components, the back rotor parts, and the front rotor parts, respectively. J_t is the moment of inertia about the travel axis, while T_f and T_b are the torques produced by the front and back motors, respectively. The helicopter is **assumed to be in SLF**, and both air drag loads and damping forces are neglected.

The above Eq. 1 can be expanded and rearranged as follows:

$$K_{rt}(V_b - V_f) = K_{rt} D = J_t \ddot{\lambda} \qquad \textbf{Equation 2}$$

$$\mathrm{G(s)} = \frac{\Lambda(s)}{D(s)} = \frac{K_{rt}}{J_t s^2} \qquad \textbf{Equation 3}$$

In Eqs. 2 and 3, K_{rt} is the Motor-Prop torque constant, V_f and V_b are the individual input voltages for the respective front and back motors, and $D(s)$ is the signal representing the difference between front and back motor voltages $(V_b - V_f)(s)$. Note that the difference between V_f and V_b is bounded by a maximum value so one could calculate the maximum acceleration of the helicopter about the travel axis if the maximum value of $(V_b - V_f)$ is known. **Note:** the helicopter is assumed to be at SLF (i.e., $V_f = V_b = 0.5*V_{sum}$) at $t = 0$.

From Eq. 3, one can see the similarity between the travel and elevation dynamic equations, which means that similar procedures as in Lab 3 can be used to produce the transfer functions for the open loop dynamics of the helicopter about the travel axis. To shorten the time in conducting the combined travel and elevation dynamics control of this lab, the transfer function of each individual group's helicopter is provided.

2.5 Pre-Lab Assignment

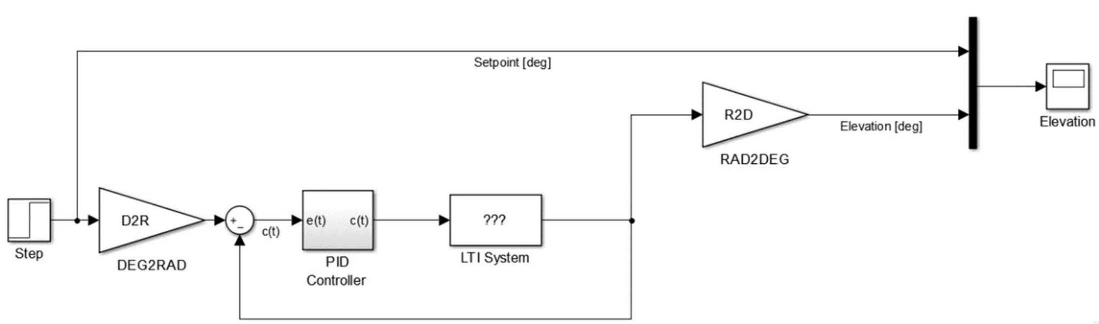
Students are required to perform the following tasks before coming to the lab:

Q	DESCRIPTION/TASK
1	Prior to attending your lab session, run MATLAB and open the Simulink library.
2	Look for the following blocks and find their names: 

3. Lab Work

3.1 Part A: Simulation Model for the Combined Elevation and Travel Controls

In this section, you will learn how to build your custom function blocks called S-Function. Then, you are required to implement a closed-loop model with PID compensators to be used for the combined elevation and travel control of the helicopter. Currently, the model includes the blocks required in simulating the elevation dynamics of the helicopter. The goal here is to simply expand the model to include the travel dynamics. Note that this is only possible because of our assumption that the helicopter is at SLF before any rotation about the travel axis occurs.

STEP	DESCRIPTION/TASK
1	Download the files for Lab 4 from D2L and put them in a Lab 4 folder on your desktop.
2	Start "**MATLAB**" and change the working directory to Lab4.
3	Open the Simulink model named "**Heli_Simulation.slx**" by double clicking it. It will look as follows:  **Figure 2 Heli Simulation Setup** This model is used for the elevation control of the helicopter. In the next step, you will use this same model structure and modify it to be used for the travel control of the helicopter.

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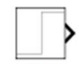
In this step, you will build the travel dynamics model using the Simulink blocks:

- Open the Simulink library again, and in the Sources library drag a Step block 

into your model and place it below the elevation dynamics model to have plenty of space to build. Double click on the block and change the "**Step time**" field to **25** and "**Final value**" field to **TRAV_SS**.
- This step block will be connected to your **D2R** S-Function block.
- Now, you need to build a PID Controller like the one in the Elevation dynamics model. Because this is generally a lengthy process, we will simply copy/paste the PID Controller from the elevation model and place it next to the "**Sum**" block.
- Once you have copy/pasted the PID block, open it and change the names of the control gains from "Kp", "Ki", and "Kd" to "**Kpt**", "**Kit**", and "**Kdt**", respectfully, throughout the block (including the names of the connections). While you are inside the model, **<u>Delete the "Controller Values" scope</u>**, then insert a brand new one from the Simulink library and connect it to the rest of the system in a similar fashion as before. Go back to the main model.
- Before you can connect all the blocks, you must change the "**List of signs**" in the "**Sum**" block to "|+-". When connected, the system should look like this:

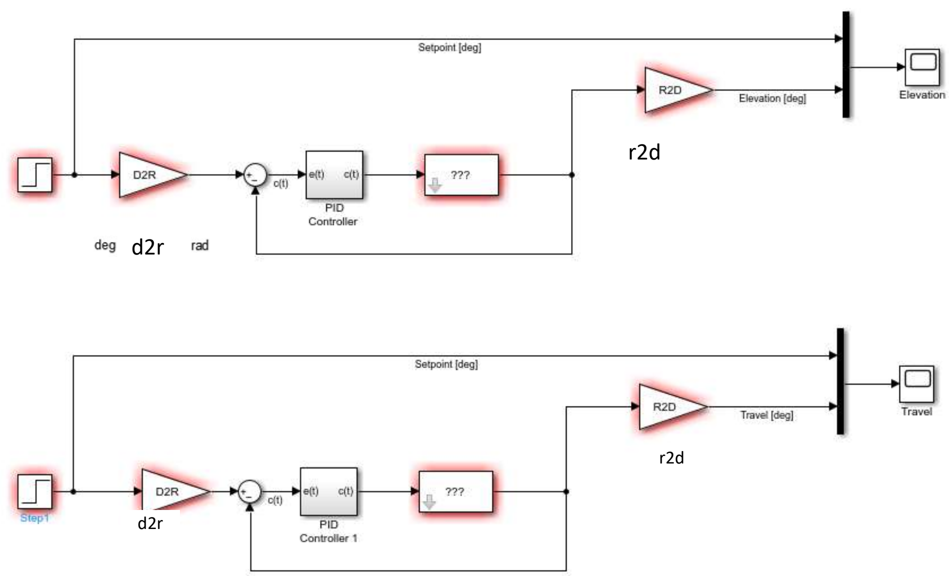


Figure 3 Simulink Model with Travel Dynamics

- **Make sure to label the wires by double clicking them and save the model on a USB stick or email it to yourself to get it ready for later.**

Note: The reference value of the proportional gain, Kp should be set to 1. This implies that the closed-loop system has a unity gain and without the presence of a compensator.

3.2 Part B: Testing Model for the Validation of the PID Controller

Now a test model will be built for testing the PID controller for the combined elevation and travel controls.

<table>
<tr><th>STEP</th><th>DESCRIPTION/TASK</th></tr>
<tr><td>1</td><td>Download the files for Lab 4 from D2L and put them in a Lab 4 folder on your desktop.</td></tr>
<tr><td>2</td><td>Start "<u>MATLAB</u>" and change the working directory to Lab4.</td></tr>
<tr><td>3</td><td>Open the Simulink file named "Heli_Controller_Testing.slx".</td></tr>
<tr><td>4</td><td>

What you see is the incomplete testing model of the elevation and travel PID controllers. In this step, you will fill in the missing piece and complete the model for future use in Labs 4.2 and 5.

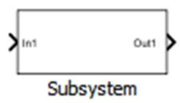
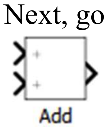
- Begin by opening the Simulink library named "**Ports & Subsystems**" and look for a "**Subsystem**" block  . Place the block next to the "**Real Plant**" subsystem.
- Open the subsystem and copy/paste its contents to produce extra in/out ports. Delete the wiring connecting the current in/out ports. Rename the in/out ports as in the following image:

Figure 3 Subsystem Setup

- Next, go into the Simulink library and in "**Math Operations**" find two "**Add**" blocks  , and a "**Gain**" block  drag them into the subsystem. Change the signs of one "**Add**" block to "**+-**", and leave the other one as is.
- What you will do now is wire up the system such that the following equations are true:

$$V_f = \frac{V_{sum}}{2} + U \quad \textbf{Equation 4}$$

$$V_b = \frac{V_{sum}}{2} - U \quad \textbf{Equation 5}$$

- Once the subsystem is completed, connect the V_f and V_b outputs to the "**Real Plant**" input blocks. Find the U and V_{sum} outputs of the PID Controllers and connect them to the subsystem you just made as inputs. The result should look as follows:

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	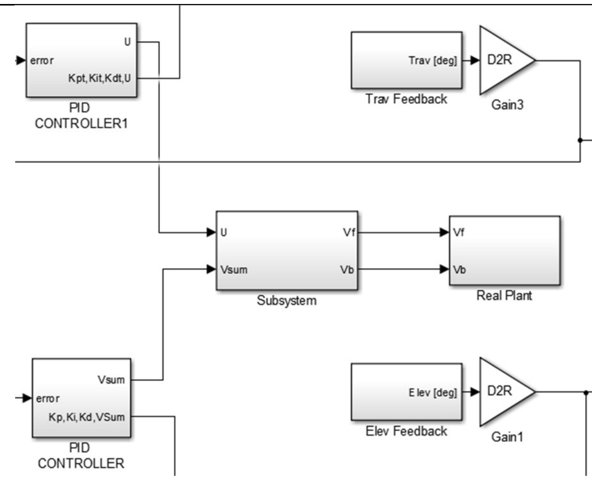 **Figure 4 User-defined Subsystem in Testing Model** • **Make sure to save the model on a USB stick or send it to your email to use in Labs 4.2 and 5.**